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Luminous Blue Variables in M33: The Extended Hot Phase of Romano's Star (GR 290)

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ABSTRACT *The Romano's Star (GR290) is an LBV in M33. Recently, the star underwent a* ***dramatic decrease in the visual****, that was accompanied by a marked increase of the spectral line excitation. Presently,* ***GR 290 appears to be in the hottest phase ever observed in an LBV****. More than 100 emission lines have been identified in the 3100—10000 A range covered by the WHT spectra, including the hydrogen Balmer and Paschen series, HeI and HeII, C III, N II-III, Si III-IV, and* ***many forbidden lines*** *of [O III], [N II], [S III], [A III] and [Fe III]. Many lines, especially the He I triplets, show a P Cygni profile with an E-A radial velocity difference of ~400 km/s. The 2008 spectrum appears quite similar to that of a typical WN8-9 star. During 2003—2009 GR 290 varied between the WN11—WN8 spectral types, with the hottest spectrum corresponding to a fainter visual magnitude. This* ***temperature-visual luminosity anticorrelation*** *suggests variation at constant* M_{bol} *. GR 290 might just present the key evidence that will help to* ***bridge the LBV and WNL evolutionary phases****.*

Luminous Blue Variables in M33

Since 2003 we have been carrying on an extensive monitoring of LBVs in the nearby galaxy M33 [1], mostly based on observations at the Italian Loiano and Asiago Observatories, with the aim of investigating the physical nature and evolutionary state of variable stars in the upper H-R diagram, and the origin of their instabilities (as marked by their S-Doradus type luminosity variations). Among the objects of our study the **Romano's Star**, (**GR 290**, also v532) is the most interesting, both for its high temperature and luminosity, and the large luminosity variations [1-6]. GR 290 is an LBV placed at about 4.2 kpc to the North-East of the M33 center, near the young OB association OB 89 (**Figure 1**).

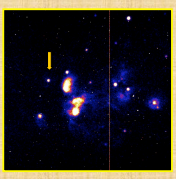


Figure 1. Hα image of the region near GR 290 (I) and the clusters OB 89 and OB 88 to the West (July 2005, Loiano Observatory).

Recently, GR 290 reached a deep minimum followed by the appearance of a very hot spectrum, the hottest so far recorded for an LBV [6]. Here we discuss the results of six years of multicolour photometry and low resolution spectroscopy, and describe new intermediate resolution spectra collected at WHT in December 2008.

The Light Curve of GR290

Figure 2 shows the recent (2003-2009) light curve of GR 290 in ***B*** (dots with error bars, [1,7]) compared with the photographic surveys of Giuliano Romano (1960-1977) [2], of Kurtev et al. (1982-1990) [3], and of Sholukhova et al. (1972-2000) [4]. The original m_{ph} have been transformed to Johnson's ***B*** magnitudes. One can see that in half a century GR 290 underwent ample luminosity variations with ***four minima in ~1960-61, 1977-80, ~2000 and 2008***. The 2008 minimum reported by us is the deepest one so far recorded. The amplitude of the photometric variations would imply a ***change in the effective radius of a factor two***.

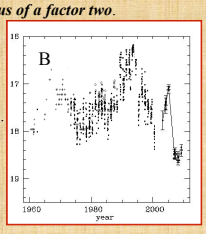
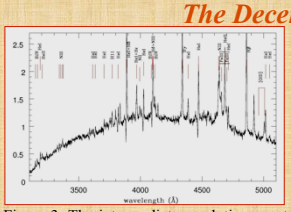


Figure 2. Blue light curve of GR290 during 1960-2009.

The December 2008 Spectrum of GR290



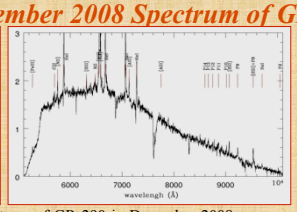


Figure 3. The intermediate resolution spectrum of GR 290 in December 2008 with some line identification (William Herschel Telescope).

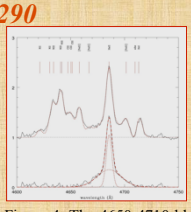


Figure 4. The 4650-4710 blend.

More than 100 emission lines have been identified in the 3100-10000 Å spectral range covered by the WHT spectra, belonging to different species, including the hydrogen Balmer and Paschen lines, He I and He II, C III, N II-N III, Si III-Si IV, and forbidden lines of [O III], [N II], [S III], [A III] and [Fe III] (**Figure 3**). The presence of the [O III] doublet indicate the presence of a massive low density, high temperature circumstellar envelope. Many lines, especially the He I triplets, show a P Cygni absorption with an E-A radial velocity difference around 400 km/s. Especially interesting is the 4630-4700 Å emission feature which is a line blend of at least N III, C III, He II and [Fe III] (**top of Figure 4**). After subtraction of the other components we found that the He II 4686 Å line also displays a broad component (**bottom of Figure 4**) that can be attributed to the WNL spectrum.

The overall spectrum resembles that of **WN8-9** stars according to the classification of Crowther & Smith [8]. The shape of the 4630-4700 Å blend is similar to that of the September 2006 spectrum, reported by Massey et al. [9], probably taken when the star had already reached the minimum phase.

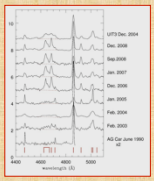


Figure 5

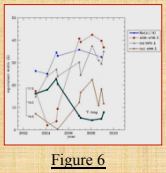


Figure 6

Spectral Variations of GR 290

During 2003-2009 we have collected many low resolution spectra covering the different luminosity phases of GR 290. As observed in other LBVs, the spectrum appeared hotter during minimum, with a marked strengthening of the ionization level of the emission line spectrum. This is best illustrated in **Figure 5** where we show the blue spectral region of GR 290 during 2003-2009. For comparison we show the spectra of ours of the Of/WN9 star UIT 3 in M33 [1], and of AG Car during a visual minimum [10]. The WHT spectrum has been resampled to the resolution of the other spectra. The 4630-4700 Å blend was weak in 2004 when the star was more luminous (V = 17-17.5), and very strong from December 2006 to present when V≅18.5. We note that in the 1998-99 spectra of GR 290 reported by Fabrika et al. [11], the 4630-4700 Å feature is not visible. GR 290 seems to have temporarily displayed a WN-type spectrum in January 1999 [4].

In **Figure 6** we show the variation of the equivalent width of some emission lines: it is evident in the figure the ***anticorrelation*** between the visual luminosity and the equivalent width of the He II line and of the 4630-4700 Å blend, while the hydrogen and neutral helium lines displayed smaller changes.

Evolutionary considerations

The time scale and amplitude of the light variations of GR 290 are typical of the ***strong-active S Dor variables*** (van Genderen [12]), such as AG Car, R 127 and S Dor itself. The anti-correlation between visual luminosity and strength of the f-feature suggests that in GR 290 the variations took probably at constant (or nearly constant) bolometric luminosity [6].

In **Figure 7** we show the representative points of GR 290 during 2003-2009 in the log equivalent width diagram of He I 5876 Å versus He II 4686 Å line. In the figure the approximate boundaries of the WN6-WN11 spectral classes proposed by Crowther & Smith [8] are drawn. As also indicated by the comparison of our spectra with the WN8-WN11 spectra illustrated by Crowther & Smith, GR290 after January 2006 has moved to the WN9-WN8 region, and presently its spectrum appears virtually indistinguishable from the classic late-WN stars.

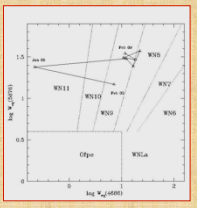


Figure 7

Figure 8 illustrate the path of GR 290 in the H-R diagram (see, e.g. [1]). The position of GR 290 and other LBVs in M33 are there compared with the evolutionary tracks of massive stars. Our observations of GR 290 show that LBVs can reach a WN8-9 spectrum in their hot phases, and come back to WN11 at maximum visual luminosity in a few years. This constitutes a key observation that will help to place better the LBVs in the evolutionary sequence of the most massive stars.

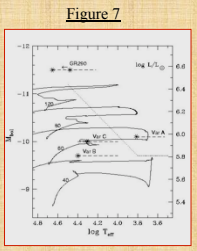


Figure 8

We acknowledge gratefully observing time granted at the WHT, Loiano & Asiago telescopes.

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